

Nuclear recoil measurements in Superheated Superconducting Granule detectors

M. Abplanalp, C. Berger, G. Czapek, U. Diggelmann, M. Furlan, A. Gabutti,
S. Janos, U. Moser, R. Pozzi, K. Pretzl, K. Schmiemann
*Laboratory for High Energy Physics, University of Bern, Sidlerstrasse 5, CH
3012 Bern, Switzerland*
D. Perret-Gallix
LAPP, Chemin de Bellevue, 74941 Annecy, France
B. van den Brandt, J.A. Konter, S. Mango
Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

Abstract

The response of Superheated Superconducting Granule (SSG) devices to nuclear recoils has been explored by irradiating SSG detectors with a 70MeV neutron beam. In the past we have tested Al SSG and more recently, measurements have been performed with Sn and Zn detectors. The aim of the experiments was to test the sensitivity of SSG detectors to recoil energies down to a few keV. In this paper, the preliminary results of the neutron irradiation of a SSG detector made of Sn granules 15-20 μ m in diameter will be discussed. For the first time, recoil energy thresholds of ~ 1 keV have been measured. ¹

1 INTRODUCTION

Superheated Superconducting Granule detectors (SSG) are being presently developed for dark matter detection [1]. Weakly interacting massive particles

¹Talk held at the Fifth International Workshop on Low Temperature Detectors in San Francisco, July 28th - August 3rd 1993

(WIMPs) can be detected measuring the recoil energy released when they interact with a nucleus inside the granule via neutral-current scatterings. A review of the status of the SSG detector development can be found in Ref.[2]. The sensitivity of SSG detectors to minimum ionizing particles [3] and to x-rays [4] has been proven in the past. To study the response of the detector to nuclear recoils in the keV range, a set of experiments have been performed by our group irradiating SSG detectors with a 70MeV neutron beam at the Paul Scherrer Institute in Villigen (Switzerland). Due to the fast transition time of the granules [5], coincidences between the scattered neutrons and the SSG were clearly established making irradiation tests of SSG a powerful probe of the response to nuclear recoils of superconducting materials.

The results of the irradiation test of a SSG detector made of Al granules 20-25 μ m in diameter are discussed in Ref.[6]. More recently (June 1993) we have performed measurements with Zn (28-30 μ m) and Sn (15-20 μ m) SSG detectors. In this paper, the preliminary results of the neutron irradiation test of the Sn SSG detector will be discussed. The measured recoil energy distributions will be compared with Monte Carlo simulations, showing that the sensitivity of Sn SSG detectors to nuclear recoils is approximately two times higher than the theoretical expectations of the global heating model. Energy thresholds of \sim 1keV were reached in the Sn SSG. Due to the limited angular resolution of the neutron detector we were not able to test the SSG sensitivity to lower recoil energies.

2 EXPERIMENTAL SETUP

The SSG detector consisted of a hollow Teflon cylinder (4mm inner diameter and 8mm inner length) filled with Sn granules imbedded in an Al₂O₃ granulate with a volume filling factor of 15%. The SSG target was surrounded by a pickup coil with 180 windings connected to a J-FET preamplifier working at room temperature. To increase the statistics we used two identical detectors made of Sn granules 15-20 μ m in diameter. Each target consisted of \sim 5 \cdot 10⁶ granules. The SSG detectors were operated in the mixing chamber of a dilution refrigerator [8] at a temperature of 40mK.

The neutron beam was generated by irradiating a beryllium target with 72MeV protons, and the residual protons were swept away by a bending magnet downstream of the Be target. The produced neutrons were sharply peaked at 70MeV and had a repetition rate of 17MHz and a bunch width of 2ns [7]. The beam was collimated down to a diameter of 3.2mm, in line with the SSG detectors. The scattered neutrons were detected using a scintillator hodoscope consisting of 18 elements placed 2 meters downstream of the SSG detectors. The range of scattering angles covered by the hodoscope was 0.02-0.5rad with a resolution of 20mrad FWHM.

We improved the setup used in the previous irradiation tests [6] using con-

crete blocks covering the sides and the top of the hodoscope to shield against neutrons and charged particles background. In addition, the neutron beam flux was measured using a thin CH_2 target positioned after the collimator and a telescope at 13 degrees to detect protons coming from $n - p$ reactions in this target. This allows an absolute evaluation of the SSG detection efficiency. To discriminate against charged particles entering or leaving the SSG, two 5mm thick scintillator veto counters were mounted before and after the cryostat window. The energy threshold of the counters was 0.15MeV. A third 2cm thick scintillator counter was located in front of the hodoscope.

3 MEASUREMENTS

The detector sensitivity to elastically scattered neutrons was measured at different detector thresholds. To select a neutron induced event within the detector, coincidences in time between the injector radio frequency, the SSG and the hodoscope signals were established. The measured distribution of the time difference between the Sn SSG and the hodoscope signals is shown in Fig. 1a . Coincidences in time between the SSG and the hodoscope signals were clearly established. The standard deviation of the distribution of the coincident SSG signals above background is 25ns. In the data analysis, only the coincidences within the hatched region were considered. The events outside this region were used to evaluate the accidental background which was subtracted from the selected sample after normalization. A further cut on the scattered neutrons time of flight of ± 1 ns was introduced in order to select elastic scattering events. The resolution was dominated by the bunch width of the beam, and therefore the accuracy in the energy measurement of the neutrons was ± 8 MeV. An elastically scattered neutron produces the phase transition (flip) of a single granule while charged particles can cause more than 1 granule to flip. The multiplicity spectrum of the flips in the Sn SSG is shown in Fig. 1b. These measurements were taken irradiating the SSG without coincidence requirements. Single flip events can be clearly distinguished from events with higher multiplicity. To reduce the background from charged particles entering the SSG and from charge exchange reactions within the SSG detector, only events with no signal from the veto counters and with a single flip multiplicity were considered.

4 RECOIL ENERGY THRESHOLD IN SSG

The energy threshold E_{th} of a single granule is given by the energy needed to rise the granule temperature from the bath T_b to the transition T_{sh} temperature. In the global heating model, the energy threshold of a granule of volume V is:

$$E_{th} = V \cdot \int_{T_b}^{T_{sh}} C(T) dT \quad (1)$$

where $C(T)$ is the superconducting specific heat [9]. From the phase diagram, the change in temperature needed to produce the phase transition can be related to the magnetic threshold $h = 1 - H_a/H_{sh}$ with H_{sh} the granule superheating field and H_a the applied field strength. The calculated energy thresholds of $17\mu\text{m}$ Sn, $22\mu\text{m}$ Al and $30\mu\text{m}$ Zn granules are compared in Fig. 2 at the temperature of 40mK.

The recoil energies due to neutral-current scatterings of dark matter particles in Sn detectors are expected to be of the order of a few keV [10]. Such thresholds can be reached with $17\mu\text{m}$ Sn granules at magnetic thresholds of $h \sim 0.01$.

To evaluate the SSG sensitivity to nuclear recoils the irradiation measurements were compared to Monte Carlo simulations using the same procedure as discussed in Ref.[6]. The scattering angle distribution of elastically scattered neutrons within the SSG was obtained by a partial wave expansion using the optical model [11]. Each SSG phase transition was simulated considering one granule randomly selected from a pool of granules with the same distributions of individual flipping fields and sizes of the SSG detector. The recoil energy E_r deposited inside the granule was determined from the scattering angle θ using the kinematical condition:

$$E_r = 4 \cdot \sin^2\left(\frac{\theta}{2}\right) \cdot \frac{M_n}{M} \cdot E_n \quad (2)$$

where E_n is the neutron energy and M_n and M are the masses of the neutron and of the target nucleus respectively. The value of E_r was then compared to the expected energy threshold of the granule. In Fig. 3 the scattering angle distributions measured with the Sn SSG at the thresholds $h=0.01$ and $h=0.025$ are compared to the calculations. The measured distributions are normalized to the neutron flux. The simulated distributions are normalized to the measured distributions. The first (0.15rad) and the second (0.4rad) diffraction maximum are well visible in the measured scattering angle distributions. The measurements show the expected shift towards higher scattering angles when the detector threshold is increased.

Previous measurements on SSG detectors, irradiated with minimum ionizing particles [3], have shown that Sn granules are a factor of two more sensitive than expected from the global heating model (equation 1). To investigate such behaviour, the measured recoil energy distributions were compared to Monte Carlo simulations which included in one case global heating and in the other case a factor of two higher sensitivity. The comparisons are shown in Fig. 4 using the same normalization as in Fig. 4. In the final data analysis the absolute detector efficiency will be evaluated. The data in Fig. 4 seem to indicate that Sn granules are more sensitive to nuclear recoils than one would expect from the global heating model. The increased sensitivity may be due to local heating effects.

The cutoff in the measured recoil energy distribution at $h=0.035$ is sharp and corresponds to an energy threshold of 5keV. At the lower threshold $h=0.025$, the

onset of the measured recoil energy distribution is at $\sim 2\text{keV}$. At the threshold $h=0.01$, the shape of the distribution at small recoil energies is dominated by the limited angular resolution of the neutron hodoscope (0.02rad) preventing us to measure the sensitivity of the SSG to recoil energies below 1keV .

5 CONCLUSIONS

The sensitivity of SSG to nuclear recoils has been explored irradiating SSG detectors with a 70MeV neutron beam. We have proven, for the first time, that SSG detectors made of $15\text{-}20\mu\text{m}$ Sn granules are sensitive down to 1keV recoil energies. The neutron irradiation experiments show, in agreement with previous measurements with minimum ionizing particles, that the sensitivity of Sn granules is a factor of two higher than expected from the global heating model. The achieved sensitivity to low recoil energies is encouraging for the use of SSG as a dark matter detector.

Acknowledgments

We would like to thank K. Borer, M. Hess, S. Lehmann, L. Martinez, F. Nydegger, J.C. Roulin and H.U. Schutz from the High Energy Physics Laboratory of the University of Bern for technical support. This work was supported by the Schweizerischer Nationalfonds zur Foerderung der wissenschaftlichen Forschung and by the Bernische Stiftung zur Foerderung der wissenschaftlichen Forschung an der Universitaet Bern.

References

- [1] M. Abplanalp et al., in these proceedings.
- [2] K. Pretzl, Part. World 1/6, 153 (1990) and K. Pretzl in these proceedings
- [3] G. Czapek et al., Nucl. Instr. and Meth. A306 572, (1991).
- [4] M. Frank et al., Nucl. Instr. and Meth. A287, 583 (1990).
- [5] M. Furlan et al., in: Low temperature detectors for neutrino and dark matter IV, eds. N.E. Booth and G.L. Salmon, (Edition Frontieres, Gif-sur-Yvette Cedex, 1992) p.21.
- [6] C. Berger et al., Nucl. Instr. and Meth. A330, 285 (1993).
- [7] R. Henneck et al., Nucl. Instr. and Meth. A259, 329 (1987).
- [8] B. van den Brandt et al., Nucl. Instr. and Meth. A289, 526 (1990).
- [9] R.D. Parks, in: Superconductivity Vol. 2, (MarcelDecker, New York, 1969) p. 779.
- [10] A. Gabutti and K. Schmiemann, Phys. Lett. B308, 411 (1993).
- [11] A. Bratenhal et al., Phys. Rev. 77, 597 (1950).

Figure captions

1. *a)* Distribution of the time difference between the SSG and the hodoscope signals for the Sn detector at $h=0.01$ *b)* Multiplicity spectrum of the Sn SSG when irradiated with the neutron beam at $h=0.005$; these events were recorded without coincidence requirements.
2. Calculated energy thresholds [keV], in the global heating model, of $17\mu\text{m}$ Sn, $22\mu\text{m}$ Al and $30\mu\text{m}$ Zn granules at 40mK.
3. Calculated (histogram) and measured (points) scattering angle distributions in the SSG detector made of $15\text{-}20\mu\text{m}$ Sn granules at the thresholds *a)* $h=0.01$ and *b)* $h=0.025$.
4. Measured (points) and calculated (histogram) recoil energy distributions in the Sn SSG detector at the thresholds *a)* $h=0.01$, *b)* $h=0.025$ and *c)* $h=0.035$. The calculated distributions at the (*bottom*) are derived from the global heating model and the ones at the (*top*) using a factor of two higher sensitivity.